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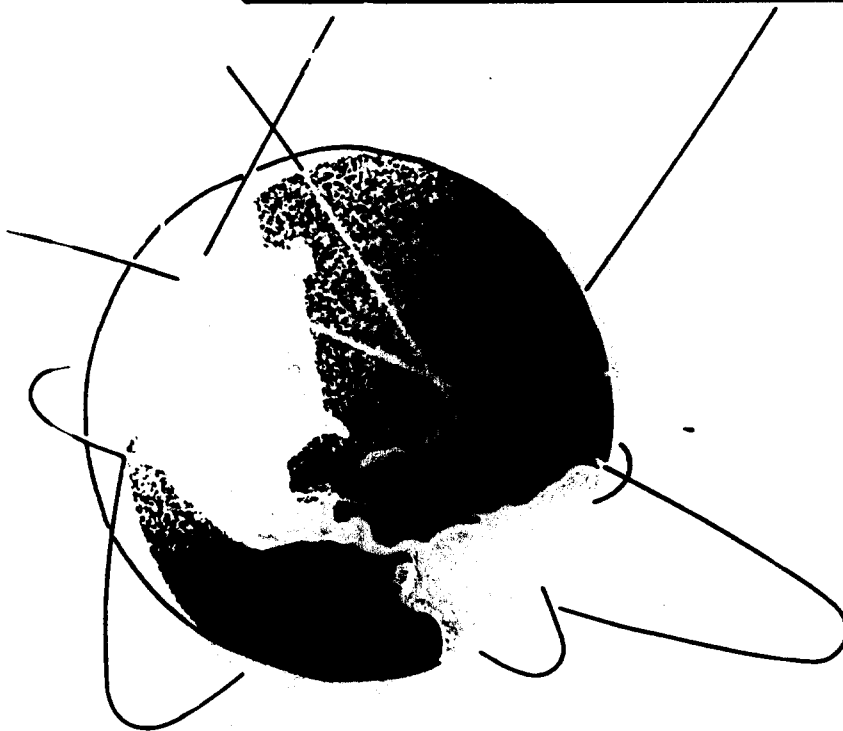
GROUND IMPACT SHOCK MITIGATION

BY

E. A. RIPPERGER

EMRL TR 1020

AUGUST 1967



ENGINEERING MECHANICS RESEARCH LABORATORY

THE UNIVERSITY OF TEXAS

AUSTIN, TEXAS

Best Available Copy

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E. A. Ripperger

FINAL REPORT

U. S. ARMY NATICK LABORATORIES
AIRDROP ENGINEERING LABORATORY

Project No. 1F121401D195

CONTRACT DA 19-129-AMC-582(N)

7 AUG 27 1967

*att: 1F121401D195-712
Natick Mass 01960
Army Natick Labs.*

ENGINEERING MECHANICS RESEARCH LABORATORY

THE UNIVERSITY OF TEXAS

Austin, Texas

August 26, 1967

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PREFACE

This report is a summary of the results of all studies conducted under Contract DA 19-129-AMC-582(N) between the University of Texas and the U.S. Army Natick Laboratories. In addition, a list of suggestions is given for guidance of designers of military vehicles which must be rugged enough for airdrop.

The report consists of four sections as follows

1. High Velocity Drops
2. Paper Honeycomb Evaluation Studies
3. Analytical Studies
4. Suggestions for Design Improvement

Engineering Mechanics Research Laboratory personnel who have contributed significantly to this work include W.L. Guyton, David Wiederanders and Garland Spretz. Helpful suggestions and constructive criticism have come from Edward J. Giebutowski and Harry Freeman of the U. S. Army Natick Laboratories.

To all of these individuals for their contributions, and to the Natick Laboratories for continued support of this research, we express our gratitude.

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ABSTRACT

Results of all investigations undertaken under Contract DA 19-129-AMC-582(N) are summarized. This includes (1) studies of high velocity airdrops of M37 3/4-ton truck, M101 3/4-ton trailer, and M2A1 105mm Howitzer, (2) development of a "drive-off" cushioning system for the 3/4-ton truck, (3) comparative study of paper honeycomb testing techniques in use at the U.S. Army Natick Laboratories and at the University of Texas, (4) development of a simple, quick honeycomb tester, and (5) analytical studies of the response of vehicles to ground impact.

In addition, rules of thumb for the guidance of designers of vehicles which may be airdropped are listed, and suggestions for improvements in the designs of specific vehicles are given.

HIGH VELOCITY DROPS

Twenty-five feet per second has been the nominal impact velocity for design computations for cushioning systems for air-drop of equipment and supplies for several years. There are certain advantages, however, to be gained by using a higher impact velocity. Not the least of these is economy. It has been shown that an appreciable economy can be effected by using more paper honeycomb to dissipate energy at impact and fewer, or smaller parachutes to retard the drop. The breakover point depends upon the relative costs of cushioning material and parachutes. Turnbow and Steyer* have shown with cost data available in 1955 that the optimum impact velocity is between 30 and 100 fps. Other advantages include a reduction in dispersion of dropped material, increased accuracy insofar as hitting the target area is concerned, and reduced time in the air.

In recognition of the advantages which may be realized, studies were initiated under Contract DA 19-129-QM1383 and continued under Contract DA 19-129-AMC-582(N) to investigate the practical problems of cushioning vehicles against high impact velocities, to discover what, if any, hidden problems may exist, to determine maximum practical impact velocities and design accelerations.

Primary objectives have been to

1. verify that vehicles can be dropped successfully at impact velocities as high as 50 fps
2. determine the design acceleration which should be used
3. work out essential details of a prototype cushioning system
4. observe the damage susceptibility of vehicles used in the studies.

Four vehicles were included in the program. One of these, the M151 (jeep) was investigated and reported upon during the previous contract period.** The other three include the M37, 3/4-

* Turnbow, J.W. and C.C. Steyer, *Cushioning for Air Drop, Part II, Air Drop Cost Analysis*, Structural Mechanics Research Laboratory, The University of Texas, Austin, 1955.

** Watson, Hal Jr., *Ground Impact Shock Mitigation M151 Utility Vehicle (Jeep)*, SMRL RM 12, Structural Mechanics Research Laboratory, The University of Texas, December 1964.

ton truck, the M101, 3/4-ton cargo trailer, and the M2A1, 105mm Howitzer.

Results of studies of these vehicles are reported in detail in

Ground Impact Shock Mitigation Cargo Truck, 3/4-Ton M37, EMRL TR 1011, December 1966.

Ground Impact Shock Mitigation Cargo Trailer M101, 3/4-Ton, EMRL TR 1025, July 1967

Ground Impact Shock Mitigation Howitzer 105mm M2A1, EMRL TR 1020, July 1967

These results are briefly summarized as follows.

M37 Truck

This vehicle was dropped a total of eight times at impact velocities ranging from 24 to 54.1 fps. Design accelerations ranged from 18.5 to 30g.

As a result of these drops, it was concluded that

1. This vehicle can be dropped to land at an impact velocity of 50 fps using essentially the same techniques used for dropping at 25 fps.

2. A design acceleration of 30g provides adequate protection for the vehicle at the highest impact velocity. This acceleration should be used even at low velocity drops to reduce the required stack heights to a minimum.

The vehicle was still operational after these drops, but some minor damage had been inflicted. There were indications, however, that more serious difficulties could develop; difficulties that would make the vehicle inoperational.

Problems most often occurred around the front motor mount and crankshaft pulley. Any permanent vertical movement of the motor on its rubber shock mounts in excess of 1/8-in., or any permanent axial movement of the motor in excess of 3/32-in. causes interference between the crankshaft pulley or the grease shield on the crankshaft and the front supporting yoke. This would not render the vehicle inoperable, but the noise it produced would probably cause a good deal of hesitation in the use of the vehicle before the damage could be assessed. More clearance and stronger frame members around the motor would take care of this problem. Also, a rugged system for limiting axial motion of

the motor should be provided.

The bed of the truck appears to be easily deformed by the 1500 lb. dead load carried during the drops. A loadspreader or pallet should be provided in the bed of the truck during actual drops if the bed is not made more rugged.

Other areas in which damage was observed were the left mount of the gear-reducer housing and the front and rear drive shafts. Damage to the drive shafts was caused by the loadspreaders during impact after rebound. This type of damage was prevented in later drops by modifying the loadspreader. The supports for the gear reducer housing need to be made more rugged. The frame is rather easily bent just behind the cab if cushioning is not properly distributed.

One potentially serious difficulty observed was closure of the contact points in the voltage regulator. This connected the generator to the battery and since the generator was not running, it acted as a dead short across the battery. The heavy current drawn welded the contact points together and only quick action kept the battery from being completely discharged.

Suggested design procedures to eliminate or minimize these difficulties will be listed later.

M101, 3/4-ton Cargo Trailer

This vehicle was included in the test program because it is representative of a class of non-powered vehicles used in large numbers by the Army. The trailer was dropped five times at impact velocities ranging from 25 to 55 fps. Design accelerations varied from 20 to 30g.

It was concluded that

1. the M101 trailer can be safely dropped at impact velocities as high as 50 fps using essentially the same techniques employed for dropping at 25 fps.
2. a 30g design acceleration provides adequate protection for the vehicle and should be used even at lower impact velocities to reduce the required stack heights and to give additional stability to the cushioning system.

Damage done to the vehicle during this test program is listed as follows

1. The heads of several of the bolts which hold the bed to the frame were broken off.

2. The bed of the vehicle was bent slightly.

3. One of the shock absorbers was bent when it came down on a cushioning stack during the rebound phase.

To minimize or eliminate these failures, the following steps should be taken.

1. Redesign the tie down bolts to eliminate the extreme stress concentration which develops at the point where the head of the bolt joins the body. In the present design, there is a very sharp reentrant corner at that point. In addition to the modification of the bolt, the tie down system should be redesigned to eliminate the unsymmetrical clip arrangement which causes a large bending moment to be applied to the bolts.

2. Make the floor of the bed of the vehicle more rugged. This can best be done by a combination of more stiffeners and heavier gauge metal in the bed itself. If the vehicle could be designed so as to allow cushioning to be placed directly against the underside of the bed, no additional ruggedness in the bed itself would be required. In any event, if the trailer is loaded when dropped, the load should be palletized.

3. The shock absorber difficulty was eliminated by a slight change in position of the rear cushioning stack.

It was noted in these drops that if the center of gravity of the load is not directly over the center of the platform (which is also the location of the resultant of the drag forces) a turning moment is applied to the vehicle during its fall and this moment is sufficient to cause appreciable rotation of the platform. Impact with the platform and vehicle in a tilted attitude is likely to be more severe than a plane or nearly plane impact.

M2A1 105mm Howitzer

This weapon was included in the high velocity drop program because it is a typical unsprung vehicle with a high concentration of mass. Also, it is highly essential that this weapon be capable of successful airdrop. Impact velocities in the test series ranged from 25 to 54 fps and design accelerations were 20 and 30g.

It was concluded that this weapon can be safely dropped at impact velocities in excess of 50 fps using essentially the same techniques used for 25 fps drops. A design acceleration of

30g provides adequate protection for the vehicle but there is some indication that the vehicle is sufficiently rugged to withstand a 40g acceleration.

The howitzer was not damaged in any detectable way by this test program. It was noted, however, that when tire pressures are unequal, the vehicle has a tendency to rebound with a rotational motion around the fore and aft horizontal axis. If tire pressures are equal, this does not occur.

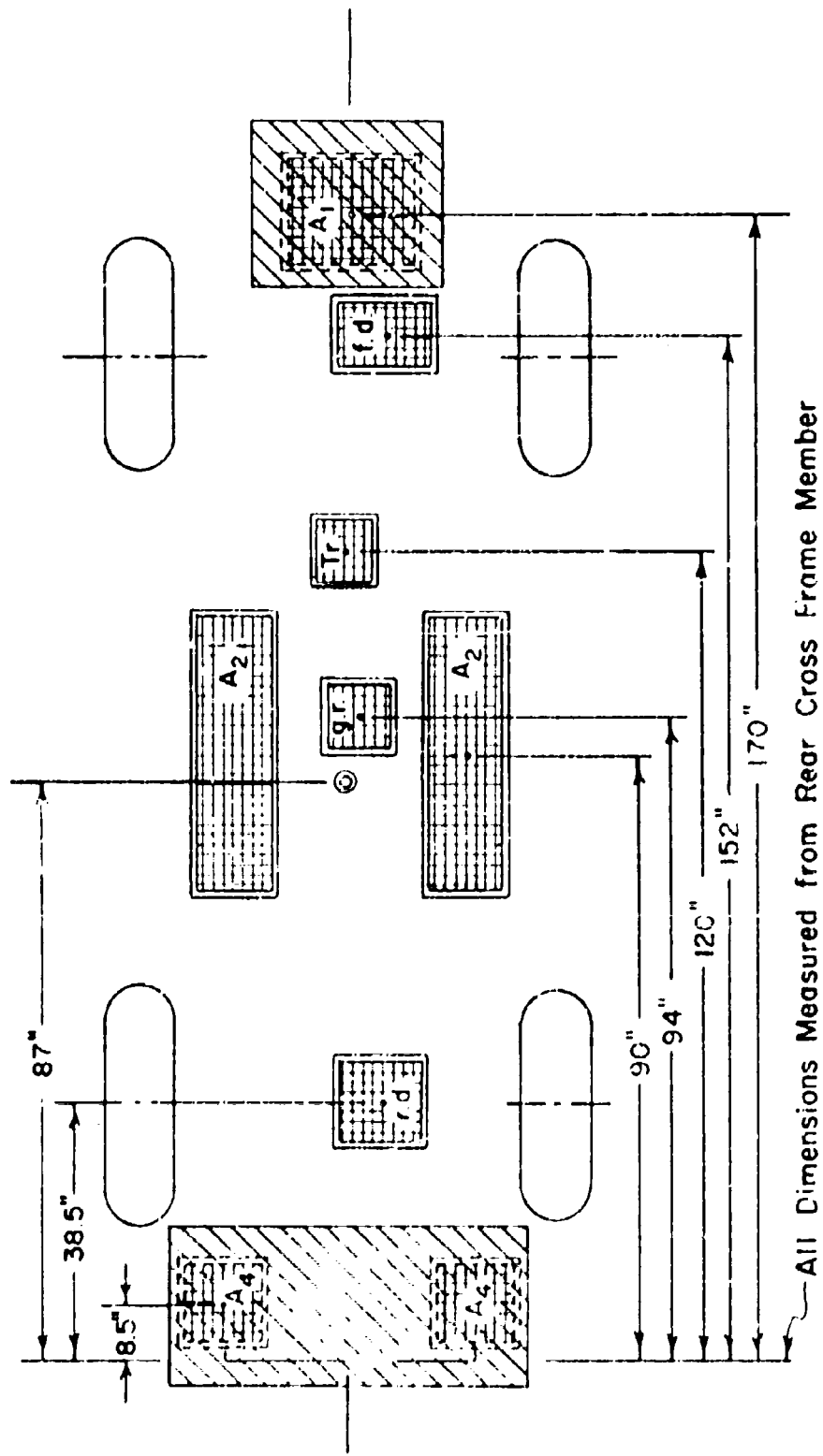
Measured average accelerations appear to agree a little more closely with design accelerations for the unsprung 105mm howitzer than for the sprung vehicles. This is consistent with the thought that the flexibility of a vehicle provides some shock mitigation for the interior parts. The evidence is not extensive enough to warrant any firm conclusions, however.

DRIVE OFF STUDIES

In past operations, airdropped vehicles have been rocked, or pushed off the cushioning system by manpower or by using one vehicle freed in that manner to pull other vehicles off their cushions. It would speed up deployment if the driver of a vehicle could simply cast off the tie down straps, get in the vehicle, and drive away. The problem of providing this capability is complicated by the variations which occur in the impact velocity. A range from 15 to 20 fps has been reported.

In addition, it is desirable to be able to drive a vehicle off of its cushioning system even though it has not been dropped. This capability would make it possible to remove vehicles from cushioning systems in forward areas where auxiliary lifting equipment may not be available.

A study was made of the drive-off problem using the M37 3/4-ton truck as the vehicle. Eight drops were made at velocities which ranged from 15 to 28 fps and with design accelerations which ranged from 17.5 to 30g. One drop was made with the truck rolled 15 degrees about the longitudinal axis. Another drop was made with the truck pitched 8 degrees about the transverse axis. This was the same truck that had previously been dropped 8 times at impact velocities as high as 54 fps. A satisfactory drive off capability was achieved by using 17.5g as the design acceleration and 9 cushioning stacks as shown in Fig. 1 and Table 1. In addition to these cushioning stacks, a ramp system of paper honeycomb, as shown in Fig. 2 was included to provide the drive-off capability. With this cushioning arrangement, the truck was dropped from 10 feet (impact velocity = 25 fps) with a tilt of 8 degrees about the transverse axis, and again from 3.5 feet (impact velocity = 15 fps) with no tilt. In



NOTE: See Table i for Stack Dimensions

© C.G. (Loaded)

Loadspreader

Crushing Stacks

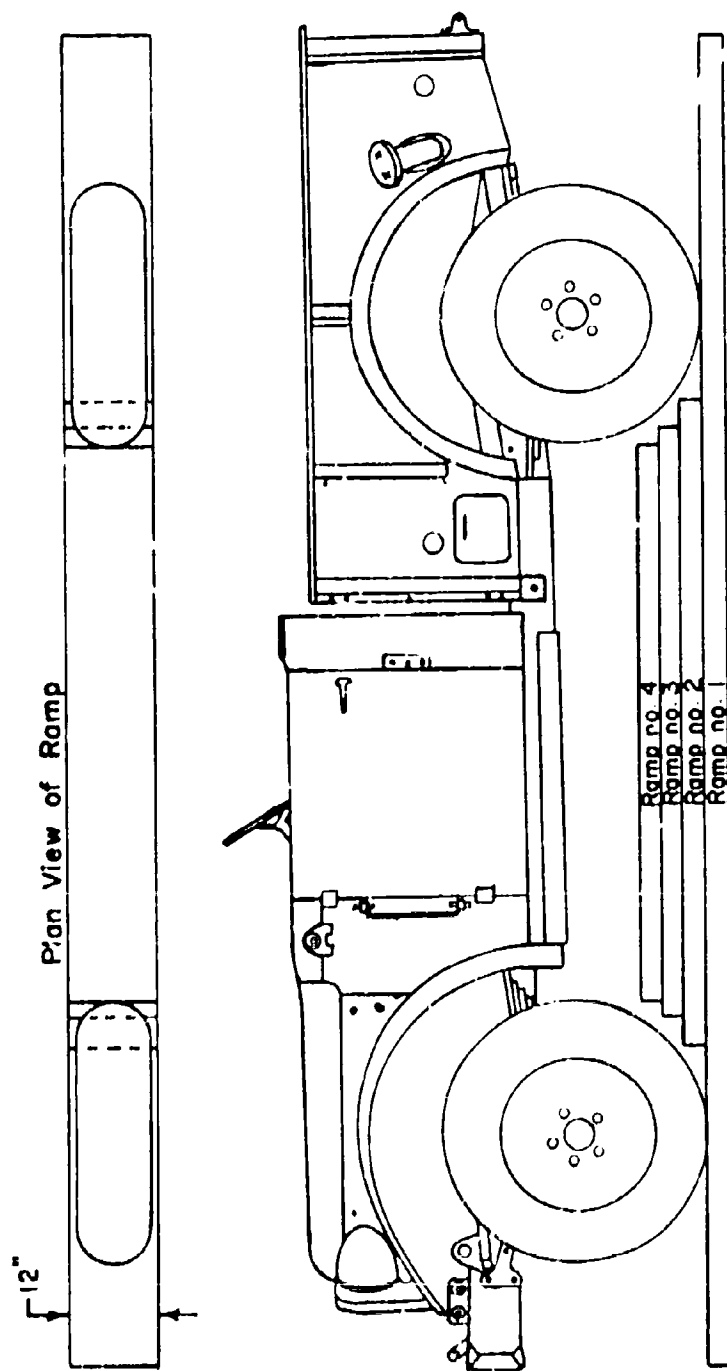
TABLE 1
Drops M37-11 through 15

Position (See Diagram)	Stack Area	Dimension	Height
		W × L	
A ₁	2.64 ft ²	1.76' × 1.5'	6 in.
A ₂	3.26 ft ²	0.9' × 3.62'	6 "
A ₄	1.25 ft ²	1.1' × 1.14'	6 "
f.d. (front differential)	1.37 ft ²	1.37' × 1.0'	6 "
g.r. (gear reducer)	0.85 ft ²	0.92' × 0.92'	6 "
Tr (transmission)	0.57 ft ²	0.85' × 0.85'	6 "
r.d. (rear differential)	1.37 ft ²	1.17' × 1.17'	6 "

Total Height including Crushing Stacks = 69-1/2 inches

NOTE: There were no wheel stacks. However, they were cushioned by the ramp system as seen in Fig. 2.

NOTE: M37-10 was made using the same stack placement as shown in Fig. 1, however, the stack areas were larger to provide for a 20g design acceleration.



Position	Size
Ramp # 1	144" x 12"
Ramp # 2	90" x 12"
Ramp # 3	84" x 12"
Ramp # 4	80" x 12"

Fig. 2 Ramp System for Drive-Off of M37 Truck

each case. it was successfully driven off the cushioning after the impact. It was also placed on the cushioning system and then driven off without a drop being made to show that the vehicle could be removed from the cushioning without special equipment in case a mission had to be aborted.

During this program of drops, some serious damage was done to the truck. The left rear engine support was broken off the housing. As a consequence, the truck could not be put in gear and driven off the platform. After the truck was repaired, the drop which produced the failure was repeated. No failure occurred. So it is concluded that the failure was not caused by one drop alone, but was a cumulative effect from the 12 previous drops of the vehicle.

Complete details of this investigation may be found in the report entitled

*Ground Impact Shock Mitigation, Drive-Off System
Development, Cargo Truck, 2 1/4-Ton M37, EMRL TR 1028,
August 1967.*

PAPER HONEYCOMB EVALUATION STUDIES

Military specifications for paper honeycomb to be used as cushioning material have in the past been based on the assumption that if paper weight, cell geometry, and glue line details are specified, the material will have the desired strength and energy dissipation capability. Wide variations were found, however, in these characteristics for materials which met all the specifications. This situation suggested that specifications should be based on required crushing strength and energy dissipation. This would in turn require some form of acceptance testing. The Engineering Mechanics Research Laboratory at the University of Texas and the U.S. Army Natick Laboratories were designated as acceptable testing organizations. Since the techniques employed by these two laboratories differ somewhat and both techniques have a subjective element in the interpretation of results, an extensive program of comparison between the two techniques was undertaken. The data used for comparative evaluation were obtained from parallel test programs conducted by the two facilities. Four 16 x 18 inch (2 ft²) test samples each, were cut at the Natick Laboratories from 3 ft. x 8 ft. honeycomb panels selected at random from a contractor's shipment. Two of each of these sets of 4 were retained at Natick and tested there. The other two were sent to the University of Texas and tested there. Results of the Natick tests and the Natick evaluation of the data were forwarded to the University of Texas. The primary basis of comparison and evaluation is the stress-strain curve. Questions arise because the stress and strain are measured and recorded separately as functions of time. These separate measurements are then combined to form the stress-strain curve. The natures of the two separate functions of time make it difficult to combine them in the stress-strain curve with any precision. It has been customary in both laboratories to "smooth" the force-time data by "hand fitting" the records. This is equivalent to replacing the original data with new data from which the violent oscillations typical of the original data have been removed. A highly subjective procedure such as this is difficult to defend in an acceptance test particularly if a shipment of cushioning material is being rejected.

In the study which was made, a more objective "least squares" type of smoothing or fitting procedure was used, as well as the "hand smoothing" on both sets of data. Results were then compared. It was found that the results of the two parallel test programs conducted by the two laboratories involved were not consistent on a sample by sample comparison. On a statistical average basis, the results were reasonably consistent. It did not appear that in any event a material might be rejected by one laboratory and accepted by the other. Differences in the

statistical results are attributable among other things, to the relatively small statistical samples which were used.

Comparisons between the two sets of data and two different methods of smoothing are given in terms of average crushing strengths as follows.

"Least Squares" Curve Fitting

	HONEYCOMB X	EMRL	Natick
Mean Values		<u>6272</u> psf	<u>6530</u> psf
Standard Deviations		670 "	674 "
	HONEYCOMB Y	EMRL	Natick
Mean Values		<u>10887</u> psf	<u>11970</u> psf
Standard Deviations		563 "	1150 "

The mean values are within 4.2% of each other in the Honeycomb X tests and 10% for Honeycomb Y tests.

"Hand Fitting"

	HONEYCOMB X	EMRL	Natick
Mean Values		<u>6272</u> psf	<u>6223</u> psf
Standard Deviations		429 "	563 "
	HONEYCOMB Y	EMRL	Natick
Mean Values		<u>11383</u> psf	<u>11185</u> psf
Standard Deviations		429 "	313 "

The mean values here are within 1% for Honeycomb X and 4.2% for Honeycomb Y.

The smaller standard deviations for the "hand fitting" procedure, as compared to the "least squares" computerized fitting procedure is attributed to the data analyzer's built in bias toward uniformity of results and his awareness of results he has already obtained.

Although the results of this investigation indicate that hand smoothing gives slightly more consistent results, the more objective "least squares" computer method of curve fitting is recommended for data reduction in acceptance testing. Results

of this investigation are reported in detail in

Comparative Evaluation of Paper Honeycomb Testing,
EMRL TR 1013, March 1967

The techniques involved in honeycomb testing of the type referred to here is too difficult and the data reduction too time consuming to be satisfactory for acceptance testing. This is especially true for manufacturers who might like to do their own testing in order to more closely control their plant output. As a consequence of these considerations, the Engineering Mechanics Research Laboratory was asked to design and build a prototype testing device which would overcome as many as possible of the objections to the techniques in use by the two laboratories, and would be simple, reliable, and inexpensive. The device which was built is shown in Fig. 3 and is described in detail in an instruction manual entitled

Dynamic Stress-Strain Curve Generator for Cushioning Materials, EMRL RM 1031, May 22, 1967

Earlier studies of paper honeycomb have shown that crushing strength is essentially independent of impact velocity. Consequently, the tester was designed to give a maximum impact velocity of 25 fps since this is obtained with a free fall of 10 feet. For this much free fall, an overall height of about 12 feet is required and this height, it was assumed, would be available in most fabrication facilities. The specified crushing strength for paper honeycomb is 6300 ± 900 psf. Hence, the tester was designed to produce at least 70% strain in a stack of two pads, 3 inches thick and 16 - 18 inches in size having that crushing strength. All of these limitations in the capability of the tester made it possible to design a very simple device which gives stress-strain curves directly without the need of any replotting, or combining of stress-time and strain-time records. The rigidity of the impacting mass, which is a 561 lb. solid slab of steel, and the columns which guide the fall of the mass minimize the extraneous signals, which made reduction of data obtained by the earlier techniques so difficult, and result in smooth stress-strain curves such as the one illustrated in Fig. 4. Detailed working drawings and an instruction book for operation of the tester have been forwarded to the Natick Laboratories. These materials are available to any interested organization.

Results of past studies of the energy absorption characteristics of paper honeycomb were summarized in a paper presented before the American Society of Mechanical Engineers Design Engineering Conference in May 1967. This paper has been designated as DE-21 by ASME and can be requested from Society Headquarters by that number.

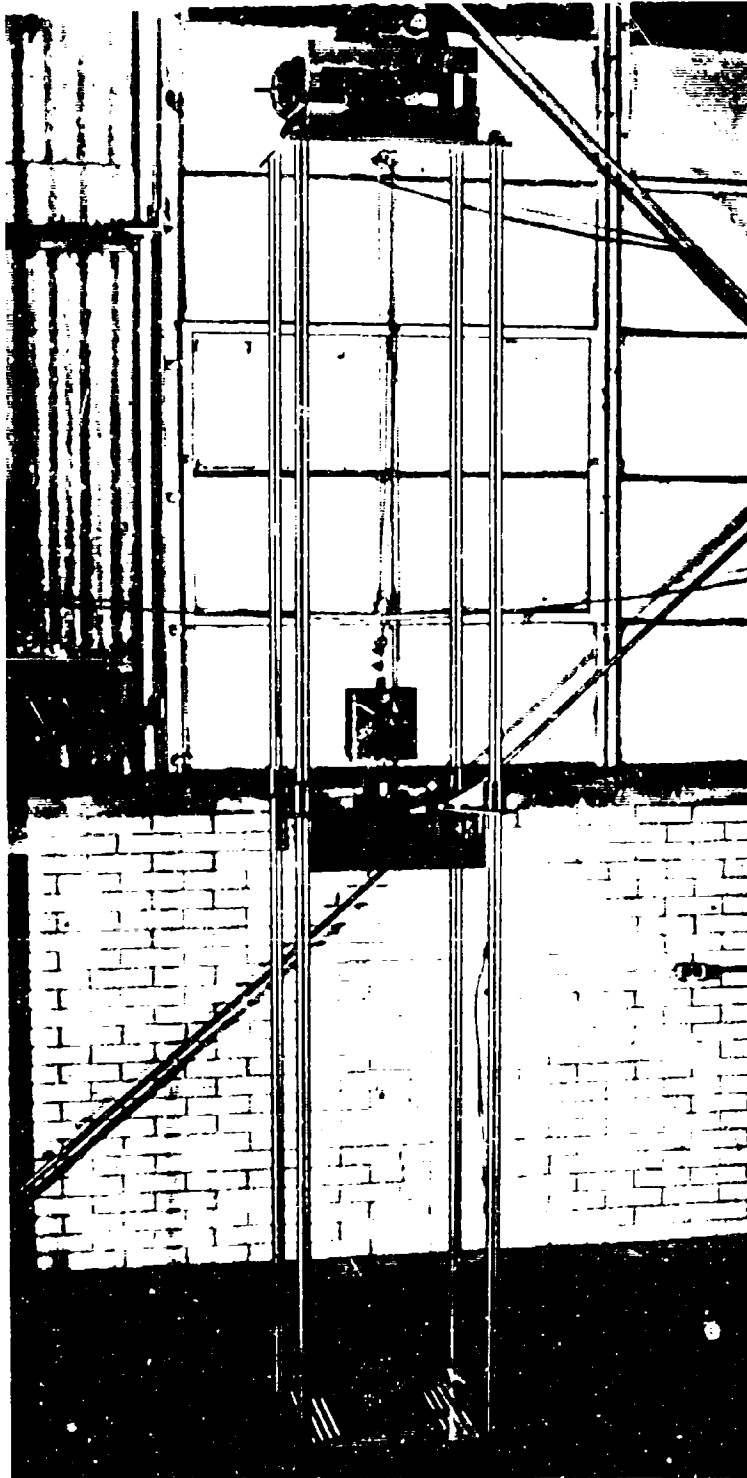


Fig. 3 Honeycomb Tester

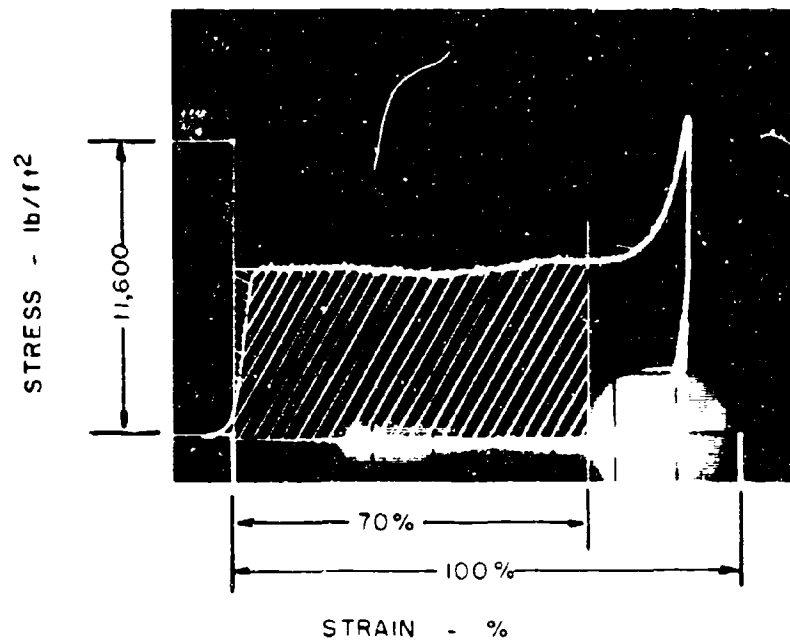


Fig. 4 Typical Stress-Strain Curve Obtained with the Honeycomb Tester.

ANALYTICAL STUDIES

No tangible progress has been made during this contract period in the analytical studies of vehicle response to impulsive loading. The general philosophy of the analytical studies started several years ago has been to analyze the structure element by element until the action of the entire structure during impulsive loading can be predicted. In this vein, the simple linear single-degree-of-freedom system was studied in detail. This was followed by the non-linear single-degree-of-freedom system and then the simplest multiple-degree-of-freedom system, the elastic beam was studied. Also an analysis was made of the response of a spring-mass system with crushable cushioning material paralleling the spring support. All of these studies provided useful information and an increased understanding of the way a complex structure reacts to impulsive loading. These earlier studies stimulated an investigation which was continued by Mr. Charles Ford, Ph.D. Candidate after he left the campus of the University and was finally brought to a conclusion in August 1967 as Mr. Ford's doctoral dissertation. This dissertation is entitled

*On a Method for Determining the Dynamic Response
Characteristics of Systems Involving Beams in
Flexure*

The problem considered in the dissertation is the determination of natural frequencies, mode shapes, steady state and transient response of systems such as plane frame works, continuous beams and beams interconnected with lumped parameter systems. Thus, it represents the most advanced extension of the original philosophy - the element by element approach. Before this dissertation was completed, an arbitrary lumped parameter system with three and then with five degrees of freedom was studied. Many computations were made and many attempts were made to obtain some generalized results, without success. The analysis bogged down in numbers. This, except for the dissertation noted above was the state of affairs so far as analysis is concerned when the present investigation began.

The first action taken under Contract DA 19-129-AMC-582(N) was a reconsideration of this earlier approach. After considerable discussion and deliberation by the personnel involved, a modification of the original approach was formulated. The essential elements of the modified approach are (1) making full use of the capabilities of the high speed digital computer available to the laboratory personnel and (2) representing the vehicle with some type of mathematical model of a lumped parameter system. The first question that arises is how simple, or how complex should the model be. Three possibilities have been considered.

These have been called: (1) the "rule of thumb" model, (2) the "complete model", and (3) the "limited model".

The "rule of thumb" model requires experience and observation and represents, as might be expected, a simplified approach that a designer can use to advantage. It does little, however, toward giving design direction from an optimization point of view. Nevertheless, design rules developed by this approach are useful to the designer and will help produce vehicles better suited for airdrop.

The "complete model" would represent an attempt to simulate by a lumped parameter system virtually every detail of the vehicle structure. No doubt such a model could be constructed. Much of this sort of thing is done in the aircraft and missile industry. However, the time and effort required to achieve a satisfactory return make this approach impractical at the present time.

To achieve results of any significance and to keep the effort within practical bounds, a compromise between the simplest and the most complicated models is required. A vehicle is a structure made up of concentrated masses connected by flexible beams. Cushioning techniques are intended to reduce the effects of the masses on the rest of the structure. The "limited model" is based on this same idea. The model consists, basically, of the large lumped masses such as the engine, transmission, differentials, winches, etc. linked by weightless beams. Smaller components such as starters and generators which are attached with very stiff fittings are considered as part of the larger mass to which they are attached. The frame and structural members are simulated by weightless, elastic beams with the proper stiffness. Cushioning forces are considered to be applied directly to the large concentrated masses insofar as possible. The vehicle is divided into several sections, each of which is considered as a free body. Cushioning forces are applied to each section in such a way as to make the resultant force pass through the C.G. of the section. Equations of motion are written and solved using matrix techniques and a digital computer. These solutions would indicate:

1. The approximate coupling between the assumed free body divisions
2. Approximate maximum stresses and locations of these stresses within the structure
3. Expected acceleration levels of the lumped masses
4. The approximate magnitudes of relative displacements between the masses in the structure.

To test the model and provide realistic feedback for orientation of studies acceleration levels of the lumped masses are measured, and the coupling forces between the free bodies are measured with strain gages. In some instances, relative displacements might also be measured.

This "limited model" analysis essentially parallels the method of cushioning design that has evolved through several years of testing, observing and relating drop predictions to fact. The analytical procedure is a logical extension of the cushioning design procedure (see the appendix of the report *Ground Impact Shock Mitigation, Cargo Truck, 3/4-Ton M37*, EMRL TR 1011, December 1966). In turn, the design of military vehicles that will be airdropped at some time should be a logical extension of both. From the concept of dividing the vehicle into separate cushionable free body subsections, with loadspreaders built in during construction of the vehicle, to the design and placement of smaller components within the vehicle, the ideas developed in the program should provide a better basis for designs appropriate to the problems encountered in airdrop.

SUGGESTIONS FOR DESIGN IMPROVEMENT

Analyses of the type outlined above have not been completed. Hence, no quantitative design procedures can be provided. However, a number of rules of thumb based on observations made in the various drop programs can be suggested. First, to put these observations in proper perspective, it should be emphasized that vehicles such as the M37 3/4-ton truck, the M151 Jeep, the M101 3/4-ton trailer, in short, all of the military vehicles that have been included in the airdrop studies are remarkably rugged. Each of these vehicles has been dropped numerous times, at high impact velocities, and some at various angles of inclination to the horizontal. Some maintenance work has been done but every vehicle was operational when the test program was completed. The M37 3/4-ton truck, for example, was dropped a total of 16 times, and although minor damage was done at times, the truck became inoperative only once. That was on the thirteenth drop when one of the motor mounts broke off. This damage is believed to have been caused by the cumulative effects of the previous 12 drops. In practice, few vehicles would ever be dropped more than once.

1. In all of the powered vehicles, the primary trouble area has been around the motor. The softness required in the motor mounts for satisfactory vibration isolation allows the motor to move an inch or more relative to the frame. Clearances between the motor and adjacent elements have not always been sufficient to avoid interference between the motor and these elements. For example, the motor of the M151 Jeep collided with a frame brace beneath the oil pan and a bolt head in this brace punched a hole in the pan. If the rubber cushions in the motor mounts are made stiffer, the average accelerations and peak accelerations of the motor will increase and the mounts will have to be strengthened. Also, if the cushions are made stiffer, the vibration isolation, particularly at low motor RPM's will be poorer. Therefore, it is recommended that the mounts be unchanged and that all elements in the vicinity of the motor be moved far enough from the motor to avoid any interference at the maximum possible motor excursion. If there is a horizontal component of velocity at impact, the flexibility of the motor mounts will allow appreciable horizontal displacement of the motor relative to the frame. Ample clearance therefore should also be provided for this type of displacement.

It was also noted in the M37 studies that the front motor support was badly designed so far as airdrop is concerned. The support is a light stamping that extends from one side of the frame to the other. The front end of the crankshaft passes through a hole in this stamping and the fan belt pulley is on

one side of the stamping and the block is on the other. Clearances between these parts are extremely small so that a very small relative displacement in the axial direction results in interference. Furthermore, the motor is attached to this brace above the crankshaft and the points of attachment to the frame. This can result in a twisting moment being applied to the brace if there is some axial acceleration of the motor. This can cause interference and damage as the brace is twisted by the resulting moment. It is recommended that all supports of this type be designed so as to minimize bending and twisting moments. A stop that would limit displacement in the axial direction would be a worthwhile addition.

The motor supports have in general been strong enough to withstand average accelerations as high as 25g. The one failure that occurred was in the housing to which the support bracket was attached rather than in the bracket itself. This suggests that these supports are strong enough for impacts controlled so as to apply the accelerating force uniformly through all the supports. However, if the impact occurs in such a way as to concentrate all of the force momentarily on one or two supports, failure may occur. Rather than make the supports much stronger to guard against this eventuality, it is more convenient and more economical to provide temporary support for the motor. Nylon strapping is specified for additional motor support during airdrop of some vehicles. The installation and removal of this temporary strapping could be greatly expedited if brackets are bolted or welded to the frame for attaching these straps. Some guide lines should also be painted on the pan to show where the auxilliary strapping should bear to properly distribute the load and to take advantage of any stiffeners that may be inside the pan.

2. Some bending of the gear reducer housing support was noted in the drops of the M37 truck. This was a cumulative damage, that is, the support was bent a little during each drop. This implies that the support is just a little under strength. An increase of 10% in strength and rigidity would probably be sufficient to prevent any appreciable bending of this support.

3. Closing of the voltage regulator points during impact such as was noted in the M37 tests can be prevented by re-orienting the regulator with respect to the direction of the impact. It is not the closure itself that causes trouble, it is the fact that the points stick and then discharge the battery that causes the trouble. Consequently, it would be preferable to leave the regulator alone and install a master switch which would disconnect the battery from the rest of the electrical system before a drop. This would protect the battery against discharge by any type of malfunction in the system. After the drop and the vehicle is ready for drive-off, the driver simply

closes the master switch to restore power to the electrical system.

4. In both the 3/4-ton truck and the 3/4-ton trailer, the floor of the bed was bent by the load of sand bags with which the vehicles were dropped. This bending has no effect on the operational characteristics of the vehicle, but it can be eliminated by making the floor out of heavier gauge material or by the addition of stiffeners. Another alternative, and one which is preferable from the standpoint of airdrop technology, is to provide some load bearing area underneath the vehicle which allows the cushion reaction to be applied directly to the bottom of the bed, rather than through the frame.

5. Avoid stress concentrations, particularly in high strength, low ductility materials. This would include such things as bolts with sharp changes in cross section. Most of the outright failures that have been observed occurred in bolts.

6. Avoid mountings in which large moments will be induced by a dynamic loading. This means that large masses should not be supported on cantilever beams, in the middle of plates, or in the middle of long beams.

7. Avoid the use of low ductility materials.

8. Provide uncluttered areas beneath the main masses to allow for direct cushioning of these masses. Vehicles, such as the M151 Jeep which have all sorts of devices such as shock absorbers, torsion bars, steering linkages, stabilizers, drive shafts, cluttering up the underneath side of the vehicle make cushioning very difficult. An important design criterion for vehicles that may be airdropped should be, "how is the location and design of 'under the body' parts going to affect the cushioning placement for the vehicle". The more clear bearing area for cushioning that can be provided beneath a vehicle, the easier the cushioning problem becomes. Such devices as plates welded or bolted to the frame at appropriate spots would be very helpful. Vehicle designers should request a preliminary cushioning layout for the vehicle and a conference with cushioning design specialists before attempting to locate bearing plates for cushioning or to redesign the underside of a vehicle to make cushioning easier.

9. Designers should bear in mind that the maximum possible deflection in a simple undamped spring-mass system subjected to a suddenly applied constant acceleration at the point of support is twice the deflection which a slowly applied acceleration of the same amplitude would produce. This maximum is seldom realized because true step type accelerations are seldom

applied in nature and there is always some damping in the system. For example, if the application of a constant 30g acceleration produces a displacement of one inch. A sudden application of the same acceleration could produce at most, a momentary two inch deflection. On the other hand, if the acceleration reaches a maximum value in a time that is one-fourth the natural period of the system and the damping is 60% of critical, the maximum deflection will be only about 1.1 inch.

10. Beams carrying no masses can be regarded as lumped-mass systems with a natural frequency equal to the fundamental frequency of the beam.

11. A beam carrying a mass can be regarded as a one degree-of-freedom spring-mass system with the mass of the beam neglected if the mass carried by the beam is 10 times or more the mass of the beam.

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R&D		
1. ORIGINATOR'S ACTIVITY (Corporate author)		2a. REPORT SECURITY CLASSIFICATION
The University of Texas Austin, Texas		Unclassified
		2b. GROUP
3. REPORT TITLE		
GROUND IMPACT SHOCK MITIGATION		
4. DESCRIPTIVE NOTES (Type of report and inclusive dates)		
5. AUTHOR(S) (Last name, first name, initial)		
Ripperberger, E. A.		
6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
August 1967	21	0
8a. CONTRACT OR GRANT NO. DA19-129-AMC-582(N)		9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO. 1F121401D195		08-47-AD
c.		9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.		FMRL TR 1029
10. AVAILABILITY LIMITATION NOTICES		
Each transmittal of this document outside the Department of Defense must have prior approval of the U. S. Army Natick Laboratories, Natick, Massachusetts.		
11. SUPPLEMENTARY NOTES		12. SPONSORING MILITARY ACTIVITY
		U. S. Army Natick Laboratories Natick, Massachusetts 01760
13. ABSTRACT		
<p>Results of all investigations undertaken under referenced contract are summarized. This includes (1) studies of high velocity airdrops of M37 3/4-ton truck, M101 3/4-ton trailer, and M2A1 105 mm Howitzer, (2) development of a "drive-off" cushioning system for the 3/4-ton truck, (3) comparative study of paper honeycomb testing techniques in use at the U.S. Army Natick Laboratories and at the University of Texas, (4) development of a simple, quick honeycomb tester, and (5) analytical studies of the response of vehicles to ground impact.</p> <p>In addition, rules of thumb for the guidance of designers of vehicles which may be airdropped are listed, and suggestions for improvements in the designs of specific vehicles are given.</p>		

DD FORM 1473

Unclassified

Security Classification

KEY WORDS	LINK A		LINK B		LINK C	
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Cushioning	8		6		9	
Drive-off systems	8		6			
Carriage vehicles	9		7		4	
Trucks	9		7		4	
Trailers	9		7		4	
Localtzers	9		7		4	
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DEFENSE DOCUMENTATION CENTER
NOTICES OF CHANGES IN CLASSIFICATION, DISTRIBUTION AND AVAILABILITY

69-21

1 November 1969

IDENTIFICATION	FORMER STATEMENT	NEW STATEMENT	AUTHORITY
AD-830 179L Texas Univ., Austin. Engineering Mechanics Research Lab. Final rept. Rept. no. EMRL-TR- 1029, USA-NIABS- TR-68-17-AD 26 Aug 67 Contract DA-19-129- AMC-582(N)	USGO: others to Army Natick Labs., Attn: AMXRES-TP, Natick, Mass.	No limitation	USANL ltr, 30 Jul 69